Title: SYSTEM CONTAINING OXYGEN ENRICHED DIESEL PARTICULATE FILTER AND METHOD THEREOF

## Cross-Reference to Related Applications

This application claims priority from U. S. Provisional Application No. 60/509720 filed 8 Oct. 2003.

## Background of the Invention

1. Field of the Invention

The present invention involves a system comprising a diesel particulate filter (catalyzed or uncatalyzed) for treatment of exhaust emissions from a compression-ignited internal combustion engine and a method that is effective for improving the performance of the diesel particulate filter by operating the engine and treating the engine exhaust emissions with the system.

2. Description of the Related Art

Future exhaust emission regulations for compression-ignited internal combustion engines in Europe and North America will require significant reductions of about 50% or more in both particulates and nitrogen oxides ($NO_x$). Diesel particulate filters (DPFs) and in particular catalyzed diesel particulate filters (CDPFs) are generally effective in removing 90% or greater of particulates which are in the form of carbon soot and hydrocarbons. However, there are several areas that could benefit from an improved performance of a DPF or CDPF to include a) compliance with future engine exhaust emission regulations, b) the engine operation practice to reduce $NO_x$ formation through exhaust gas recirculation which decreases the oxygen concentration in the engine exhaust emissions available for oxidation of particulates, and c) the general buildup of soot on a DPF or CDPF which can result in loss of fuel economy and engine wear due to excessive back pressure on the engine as well as mechanical failure of the DPF or CDPF due to an uncontrolled combustion of the soot.

The Derwent WPI abstract of Japanese Publication No. JP 2002/188427A discloses a bellows-shaped catalyzed diesel particulate filter which includes a power

supply terminal for heating a catalyst layer and an air pump for supplying air to a chamber in which the particulate filter is installed.

The Derwent WPI abstract of German Publication No. DE 10137050A1 discloses treatment of exhaust from an internal combustion engine, especially a diesel engine, that involves a particulate filter which can include a supplementary heating unit, a control unit, and a unit for supplying air to the exhaust where the particulate filter can be regenerated without a reduction in engine power.

Vigeland et al. in U. S. Patent No. 6,503,296B1 disclose a dense single phase membrane having both high ionic and electronic conductivity and capable of separating oxygen from an oxygen containing gaseous mixture where the separated oxygen can be used in catalytic and noncatalytic processes where oxygen is one of the reactants.

Kakwani et al. in International Publication No. WO 02/14657A1 disclose a diesel engine aftertreatment exhaust system that uses a combination of a catalyzed soot filter and a urea selective catalytic reduction catalyst for simultaneous reduction of particulate matter and $NO_x$.

Ellmer et al. in U. S. Patent No. 6,637204 disclose a device and method for the heating of a catalytic converter for a supercharged internal combustion engine.

It has now been found that the performance of a diesel particulate filter (catalyzed or uncatalyzed) can be significantly improved by enriching or increasing the oxygen content of exhaust emissions that flow through the particulate filter.

## Summary of the Invention

An object of the present invention is to improve the performance of a diesel particulate filter or catalyzed diesel particulate filter in a compression-ignited internal combustion engine.

Another object of the invention is to lower the temperature for regeneration of a diesel particulate filter or catalyzed diesel particulate filter in a compression-ignited internal combustion engine.

A further object of this invention is to improve exhaust emissions performance of a diesel particulate filter or catalyzed diesel particulate filter in a compression-ignited internal combustion engine for the reduction of soot, hydrocarbons including polyaromatic hydrocarbons, aldehydes and carbon monoxide.

An additional object of the present invention is to improve the durability of a diesel particulate filter or catalyzed diesel particulate filter in a compression-ignited internal combustion engine.

Yet an additional object of this invention is to improve the fuel economy of a compression-ignited internal combustion engine.

Still a further object of the invention is to improve wear performance of a compression-ignited internal combustion engine.

Additional objects and advantages of the present invention will be set forth in the Detailed Description which follows and, in part, will be obvious from the Detailed Description or may be learned by the practice of the invention. The objects and advantages of the invention may be realized by means of the instrumentalities and combinations pointed out in the appended claims.

To achieve the foregoing objects in accordance with the present invention as described and claimed herein, a system for treatment of exhaust emissions from a compression-ignited internal combustion engine comprises (A) a superatmospheric-pressurized source of gaseous oxygen, (B) an inlet for the gaseous oxygen from the superatmospheric-pressurized source wherein the exhaust emissions from the engine flow past the inlet and form a mixture with the gaseous oxygen from the inlet, and (C) a diesel particulate filter or catalyzed diesel particulate filter through which the mixture of exhaust emissions from the engine and gaseous oxygen from the inlet flows, wherein the oxygen content of the mixture is greater than the oxygen content of the exhaust emissions from the engine.

In another embodiment of this invention the above described exhaust emissions treatment system comprises one or more additional components which is or are taken from (D) at least one heat source, (E) a control unit, (F) at least one component selected from the group consisting of a diesel oxidation catalyst, a selective catalytic reduction catalyst and a lean $NO_x$ catalyst, and (G) an outlet for recirculating a portion of the exhaust emissions from the engine to an air intake of a combustion system of the engine.

In a further embodiment of the invention a method for improving the performance of a diesel particulate filter or catalyzed diesel particulate filter in a compression-ignited internal combustion engine comprises operating the engine and treating the exhaust emissions from the engine with the above described exhaust emissions treatment system

comprising components (A), (B) and (C) and optionally one or more of the components (D), (E), (F) and (G).

## Detailed Description of the Invention

The present invention comprises a system for treatment of exhaust emissions from a compression-ignited internal combustion engine that comprises (A) a superatmospheric-pressurized source of gaseous oxygen, (B) an inlet for the gaseous oxygen from the superatmospheric-pressurized source wherein the exhaust emissions from the engine flow past the inlet and form a mixture with the gaseous oxygen from the inlet, and (C) a diesel particulate filter or catalyzed diesel particulate filter through which the mixture of exhaust emissions from the engine and gaseous oxygen from the inlet flows, wherein the oxygen content of the mixture is greater than the oxygen content of the exhaust emissions from the engine.

In an embodiment of the invention for the system for treating exhaust emissions as described throughout this application, the gaseous oxygen from a superatmospheric-pressurized source or from atmospheric air is continuously introduced into the inlet for mixing with the engine exhaust emissions during operation of the compression-ignited internal combustion engine. In a further embodiment of the invention for the system for treating exhaust emissions as described throughout the application, the gaseous oxygen from a superatmospheric-pressurized source or from atmospheric air is intermittently introduced into the inlet for mixing with the engine exhaust emissions during the operation of the engine which can be based on operating parameters of the engine and/or exhaust system comprising for example exhaust emissions temperature, diesel particulate filter (catalyzed or uncatalyzed) temperature, engine back pressure, or a combination thereof.

The superatmospheric-pressurized source of gaseous oxygen (A) can be any pressurized source of oxygen that can be introduced into the exhaust system of a compression-ignited internal combustion engine and that upon mixing with exhaust emissions from the engine forms a mixture having an oxygen content greater than the oxygen content of the exhaust emissions from the engine. The source of gaseous oxygen can be air, oxygen, an oxygen containing gas, or a mixture thereof. The oxygen containing gas can have an oxygen content of 1 to 99% by volume, and in other instances can have an oxygen content greater than 21% by volume to 99% by volume, greater than

21% by volume to 70% by volume, and greater than 21% by volume to 40% by volume. The source of gaseous oxygen will generally have a pressure greater than the atmospheric pressure, and in other instances will have a pressure that is 1.05 to 1000 times the atmospheric pressure or 1.1 to 500 times the atmospheric pressure. In another embodiment of the invention the source of the gaseous oxygen can have a pressure greater than the exhaust pressure of the exhaust system, and in several instances the source of the gaseous oxygen can have a pressure that is 1.05 to 1000 times or 1.1 to 500 times the exhaust pressure of the exhaust system. The source of gaseous oxygen can raise the oxygen content of the mixture, that forms from exhaust emissions from the engine and the source of gaseous oxygen, to be greater than the oxygen content of the exhaust emissions from the engine by at least 0.1% by volume, and in other instances by at least 1% by volume, by at least 2% by volume, by at least 3% by volume, by at least 4% by volume, by at least 5% by volume, by at least 6% by volume and by at least 7% by volume. In another embodiment of the invention the oxygen content of the mixture from the engine exhaust emissions and the source of gaseous oxygen can be 10.1 to 99% by volume, and in other embodiments can be 11 to 50% by volume, and 12 to 30% by volume. The superatmospheric-pressurized source of gaseous oxygen can comprise a compressor, a blower, a compressed gas storage container, or a mixture thereof. The gas in the compressed gas storage container can be air, oxygen, or an oxygen containing gas having an oxygen content as described hereinabove. In an embodiment of the invention the source of gaseous oxygen can be obtained from a compressor or blower that is normally present such as for example a turbocharger, a supercharger, and a compressor for air brakes. In another embodiment of this invention the source of gaseous oxygen can be obtained from a dedicated compressor or blower which can be powered by an electric motor, the internal combustion engine, the exhaust flow of the engine, or a mixture thereof. In a further embodiment of the present invention the source of gaseous oxygen can be obtained from a combination of a compressor or blower normally present and a dedicated compressor or blower. The compressors and/or blowers of this invention can compress or blow air and in certain instances oxygen or an oxygen containing gas having an oxygen content as described hereinabove.

The source of gaseous oxygen can further comprise, in addition to a compressor, a blower, a compressed gas storage container, or a mixture thereof, a permeable membrane

wherein the membrane provides oxygen or a gas having an increased oxygen content from mixture of gases that includes oxygen. Generally the mixture of gases that includes oxygen, from which the permeable membrane provides oxygen or a gas having an increased oxygen content, is air. In an embodiment of the invention the permeable membrane is an organic polymeric permeable membrane, as described in U.S. Patent No. 4,537,606, having a higher permeability for oxygen relative to nitrogen. Organic polymers which can function as permeable membranes include for example poly(butadiene), ethyl cellulose, poly(propylene), poly(styrene), poly(dimethylsiloxane) and polysulfone. Permeable membranes from organic polymers are available commercially and include an oxygen enriching membrane Prism® PA4050 from Air Products. In another embodiment of this invention the permeable membrane is a dense single phase permeable membrane from lanthanide-transition metal oxide material having both high ionic and electronic conductivity and capable of separating oxygen from a mixture of gases that includes oxygen as described in U.S. Patent No. 6,503,296. In an embodiment of the invention a blower or compressor drives air through an organic polymeric permeable membrane, and the oxygen enriched gas exiting the permeable membrane is stored in a compressed gas storage container for later use and/or is allowed to enter the engine exhaust system. In another embodiment of the invention a dense single phase permeable membrane produces oxygen from air, the produced oxygen is compressed with a compressor or blower, and the compressed oxygen is stored in a compressed gas storage container for future use and/or allowed to enter the engine exhaust system.

The system of the present invention for treating exhaust emissions from a compression-ignited internal combustion engine can comprise (B) an inlet for the gaseous oxygen of component (A) where the inlet is generally downstream from the entrance of the engine exhaust emissions into the exhaust system and generally upstream from a DPF or CDPF. The inlet of component (B) can include a valve for controlling the flow and flow rate of the gaseous oxygen of component (A) into the exhaust system.

The system of the present invention for treating the exhaust emissions from a compression-ignited internal combustion engine can comprise (C) a diesel particulate filter (DPF) or a catalyzed diesel particulate filter (CDPF). In an embodiment of the invention the treatment system for engine exhaust emissions comprises a CDPF. The

DPF or CDPF can include filters from a porous ceramic wall-flow monolith, a wire mesh, wound or packed ceramic fiber media, an open-cell ceramic foam and a sintered metal. In an embodiment of the invention the DPF or CDPF is from a porous wall-flow ceramic monolith. The porous wall-flow ceramic monolith can be composed of one or more ceramic materials such as for example cordierite, spodumene, zirconium silicate, alumina, silica, zirconia, silicon carbide, silicon nitride, mullite, and alumina-silica-magnesia. The CDPF can be prepared by coating a filter substrate, such as a porous wall-flow ceramic monolith from cordierite, with a catalyst which is generally a metal or metal oxide where the metal can be platinum, palladium, rhodium, ruthenium, vanadium, magnesium, calcium, strontium, barium, copper, silver, or a mixture thereof. The catalyst typically includes platinum due to its high catalytic activity which substantially lowers the temperature for regeneration of the CDPF from trapped carbon soot. The preparation of a CDPF, as described in International Publication No. WO 02/14657, generally involves impregnating the filter substrate with a solution or slurry, which is usually water based, of a catalyst precursor followed by drying and calcining to leave a metal or metal oxide catalyst. The preparation of a CDPF can also include application of an oxide catalyst carrier, such as alumina or silica or zirconia, to the filter substrate prior to application of the catalyst to enhance catalyst surface activity and durability. A CDPF can also contain a promoter to include an alkaline earth metal oxide such as magnesium oxide or a rare earth metal oxide such as cerium dioxide. The catalyst coating on the filter substrate, such as a wall-flow ceramic monolith, can comprise 5 to 150 g/ft$^3$ of a catalyst metal, and in other instances can comprise 15 to 100, 25 to 60, or 40 to 85 g/ft$^3$ of a catalyst metal. Catalyzed diesel particulate filters are available commercially from various suppliers including Engelhard Corporation.

In an embodiment of the invention the DPF or CDPF of component (C) can comprise two or more sections where the sections can run from the entrance to the exit of the filter and where each section is capable of being separately regenerated while the other section or sections continue to filter engine exhaust emissions. The sections can be separated from each other by some means to include a semipermeable barrier such as ceramic glass beads or by an impermeable barrier such as a nonporous ceramic or metal. The sectioned filter can have a means such as a baffle for directing a flow of the gaseous oxygen from component (A) to a section of the filter for regeneration and for directing a

flow of engine exhaust emissions to the other section or sections of the filter. The means for directing a flow of the gaseous oxygen of component (A) and the engine exhaust emissions will generally be changeable so that each section of the filter can be regenerated under a flow of the gaseous oxygen from component (A). In another embodiment of this invention the DPF or CDPF can comprise two or more separate units that are parallel and in close proximity to each other. A means such as a manifold can selectively deliver gaseous oxygen of component (A) to one of the units of the filter for regeneration while another means such as a second manifold can selectively deliver engine exhaust emissions to the other unit or units of the filter.

In an embodiment of the invention as described throughout this application, the system for treatment of exhaust emissions from a compression-ignited internal combustion engine comprises atmospheric air as a source of gaseous oxygen, an inlet for the atmospheric air wherein exhaust emissions from the engine flow through a venturi which draws in the atmospheric air through the inlet forming a mixture of exhaust emissions and atmospheric air, and a diesel particulate filter or catalyzed diesel particulate filter through which the mixture of exhaust emissions and atmospheric air flows wherein the oxygen content of the mixture is greater than the oxygen content of the exhaust emissions from the engine.

The system of the present invention as described above for treating exhaust emissions from a compression-ignited internal combustion engine can further comprise one or more additional components taken from (D) at least one heat source, (E) a control unit, (F) at least one component selected from the group consisting of a diesel oxidation catalyst, a selective catalytic reduction catalyst and a lean $NO_x$ catalyst, and (G) an outlet for recirculating a portion of the exhaust emissions from the engine to an air intake of a combustion system of the engine. The one or more additional components (D), (E), (F) and (G) can be present to further improve the performance of the exhaust emissions treatment system.

The heat source of component (D) can be any source of heat to include a heater, a heat exchanger, and/or the injection and combustion of fuel in the exhaust system. One or more heat sources can be present to heat the exhaust emissions from the engine, to heat the gaseous oxygen of component (A), to heat a DPF or CDPF of component (C), to heat the one or more catalysts of component (F), or a combination thereof. The heater of

component (D) is usually an electrical heater to include for example a heating filament. The heat exchanger of component (D) can obtain surplus heat from any heat source of the engine and/or related systems comprising for example heat from the engine, heat from the engine exhaust emissions, heat from various air conditioners and/or coolers, heat from an air brake system, heat from the DPF or CDPF outlet emissions, or a combination thereof.

The control unit of component (E) is usually an electronic control unit and can be a computer such as for example the engine's electronic command module. The control unit (E) can control the components (A), (B), (C), (D), (F), (G) and/or their related subcomponents as described throughout this disclosure based on sensors which are generally located throughout the exhaust system and which can measure temperature, pressure and composition of the exhaust system gases. The control unit generally functions to optimize the performance of the exhaust treatment system.

Component (F) of the present invention can comprise at least one catalyst selected from a diesel oxidation catalyst (DOC), a selective catalytic reduction (SCR) catalyst, and a lean $NO_x$ catalyst. In an embodiment of the invention the exhaust treatment system includes a DOC. In another embodiment of the present invention the exhaust treatment system includes a SCR catalyst or a lean $NO_x$ catalyst. In still another embodiment of this invention the exhaust treatment system includes a DOC and either a SCR catalyst or a lean $NO_x$ catalyst.

A DOC when present in the exhaust treatment system can be located anywhere in the system which will improve performance, but is generally located either upstream from components (B) and (C) or downstream of a SCR catalyst or lean $NO_x$ catalyst. A DOC can oxidize various components in the exhaust emissions from the engine including carbon monoxide and hydrocarbons as well as any surplus reductants such as ammonia or hydrocarbons from a SCR catalyst or lean NOx catalyst as described below. A DOC is generally a catalyzed ceramic or metallic monolith that is sufficiently large in size, in terms of volume capacity and cell size, so that it does not readily become clogged with carbon soot. A DOC can be prepared by applying to a monolith substrate a washcoat layer which can include alumina with a zeolite or a rare earth metal or an alkaline earth metal followed by application of a catalyst where the metal of the catalyst can be platinum, palladium or a mixture thereof. Diesel oxidation catalysts are available commercially from several suppliers.

A SCR or lean $NO_x$ catalyst when present in the exhaust treatment system will generally be located downstream of the DPF or CDPF of component (C). Both a SCR or a lean $NO_x$ catalyst can reduce $NO_x$ from the engine exhaust emissions to nitrogen using a reductant that is respectively ammonia, or an ammonia precursor of aqueous urea, or hydrocarbons from the fuel. The reductant can be introduced into the exhaust system from a valved inlet upstream of the SCR or lean $NO_x$ catalyst. A SCR catalyst, as described in International Publication No. WO 02/14657, can include a flow-through monolith to which is applied a catalyst and a transition metal oxide binder where the catalyst can be an iron or copper or titanium/vanadium exchanged zeolite. A lean $NO_x$ catalyst, as described in International Publication No. WO 02/14657, can be of the low or high temperature type. The low temperature type is platinum based that can use a platinum/zeolite or platinum/alumina catalyst. The high temperature type uses a base metal/zeolite catalyst such as copper/zeolite. Both SCR and lean $NO_x$ catalysts are commercially available with SCR catalysts being supplied by Engelhard Corporation.

Component (G) of the present invention can comprise an outlet for exhaust gas recirculation which can be located throughout the exhaust treatment system, but it is generally located just downstream from the entrance of the exhaust emissions from the engine into the exhaust treatment system. The outlet of component (G) can include a valve for controlling the flow and flow rate of exhaust emissions back to an air intake of the combustion system of the engine.

A method of the present invention for improving the performance of a diesel particulate filter or catalyzed diesel particulate filter in a compression-ignited internal combustion engine comprises operating the engine and treating the exhaust emissions from the engine with the exhaust emission treatment system as described throughout this disclosure comprising components (A), (B) and (C) and optionally one or more of the components (D), (E), (F) and (G). As indicated above in the Summary of the Invention section the exhaust emissions treatment system and method of the present invention for using the system in the operation of a compression-ignited internal combustion engine improves the performance of a DPF or CDPF which can result in a lower temperature for regeneration of the DPF or CDPF, a general improvement in exhaust emissions performance in terms of soot and hydrocarbons and carbon monoxide, improved durability of the DPF or CDPF, improved fuel economy, and improved engine wear

performance. In an embodiment the system and method of the present invention improve the performance of a DPF or CDPF in a compression-ignited internal combustion engine that employs exhaust gas recirculation to help control $NO_x$ generation. While exhaust gas recirculation can reduce $NO_x$ generation, it can adversely affect the performance of a DPF or CDPF since it decreases the oxygen content of the exhaust emissions from the engine which is available for oxidation of soot. In another embodiment of the method of the present invention the temperature for regeneration of the DPF or CDPF is decreased by 1 to 200°C, and in other embodiments is decreased by 5 to 150°C, and by 10 to 100°C. In a further embodiment of the method of the invention the rate for regeneration of the DPF or CDPF is increased.

Catalyzed Diesel Particulate Filter Evaluations

A diesel engine was operated on a dynamometer in a series of CDPF evaluations that included three base line runs and two runs in which compressed air was used to increase the oxygen content of the gases passing through the CDPF. Measurements included the gas temperature near the entrance of the CDPF, pressure in the exhaust system, and oxygen content in the exhaust system upstream of the CDPF. Regeneration occurred based on the maximum pressure drops obtained for the base line runs at 357°C and 9.2% by volume oxygen and for the compressed air runs at 289°C and 15.7% by volume oxygen.

Each of the documents referred to in this Detailed Description of the Invention section is incorporated herein by reference. All numerical quantities in this application used to describe or claim the present invention are understood to be modified by the word "about" except where explicitly indicated otherwise. All chemical treatments or contents throughout this application regarding the present invention are understood to be as actives unless indicated otherwise even though solvents or diluents may be present.